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OVERVIEW OF RECENT TRITIUM EXPERIMENTS IN TPE

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Tritium retention in plasma-facing components influences the design, operation, and lifetime of fusion devices such as ITER. Most of the retention studies were carried out with the use of either hydrogen or deuterium. Tritium Plasma Experiment is a unique linear plasma device that can handle radioactive fusion fuel of tritium, toxic material of beryllium, and neutron-irradiated material. A tritium depth profiling method up to mm range was developed using a tritium imaging plate and a diamond wire saw. A series of tritium experiments (T_2/D_2 ratio: 0.2 and 0.5 %) was performed to investigate tritium depth profiling in bulk tungsten, and the results shows that tritium is migrated into bulk tungsten up to mm range.

I. INTRODUCTION

Linear plasma devices have been widely used to investigate various plasma wall interaction (PWI) phenomena due to the well-controlled uniform distribution of ion flux density, electron density, incident ion energy, and sample temperature. Nevertheless, most of PWI studies in linear plasma devices have been carried out with using either hydrogen or deuterium, and the introduction of the radioactive hydrogen isotope, tritium, is necessary to create deuterium-tritium (D-T) fusion reaction in the ITER and a future DEMO reactor. Tritium Plasma Experiment (TPE) is a unique linear plasma device that can handle radioactive fusion fuel of tritium, toxic material of beryllium, and neutron-irradiated material. The depth profile of hydrogen isotopes in tungsten has been characterized up to several μm by either nuclear reaction analysis or secondary ion mass spectroscopy, and there is a need for a depth profiling method to mm range in order to characterize tritium behaviors in entire plasma facing components (PFCs) thickness (mm to cm range) of the ITER divertor and first wall. The use of tritium improves the sensitivity of the retention measurement significantly, and a tritium depth profiling method up to mm range was developed using a tritium imaging plate (TIP) and a diamond wire saw (DWS). A series of tritium experiments was performed to investigate tritium depth profiling in bulk tungsten, a candidate material for ITER PFCs. The objective of this paper is to give an overview of tritium handling system in TPE, and summarize the results from the recent tritium experiments.

II. EXPERIMENTAL APPARATUS

II.A. Tritium plasma experiment (TPE)

The schematic of TPE is shown in Figure 1. TPE source is reflex-arc plasma source that consists of a negatively biased lanthanum hexaboride (LaB_6) cathode and a water-cooled grounded stainless steel anode. Incident ions were assumed to be primarily singly ionized species (D^+ or T^+), and the incident ion energy is determined by the potential difference between the bias voltage and the plasma space potential. Sample temperature is controlled by changing the materials (to vary thermal conductivity) and geometries (to vary effective thermal diffusion area) of the heat sinks between the sample and the water-cooled copper plate. The sample temperature is measured by a type-K thermocouple attached to the back of the sample, and the stable sample temperature range from 300 to 1100 K was achieved[1].

Langmuir probe is used to measure plasma parameters (electron temperature, electron density, ion flux density, plasma space potential, and float potential), and it can be mounted at two different axial positions (either at target side or source side) as illustrated in the Figure 1. For the deuterium/tritium retention study, a thermal desorption spectroscopy (TDS) system outside the glovebox is used. TDS is equipped with two quadrupole mass spectrometers: a broad range one for AMU 1-50 and a high resolution one for AMU 1-6. The detail of the retention studies is in elsewhere[1].

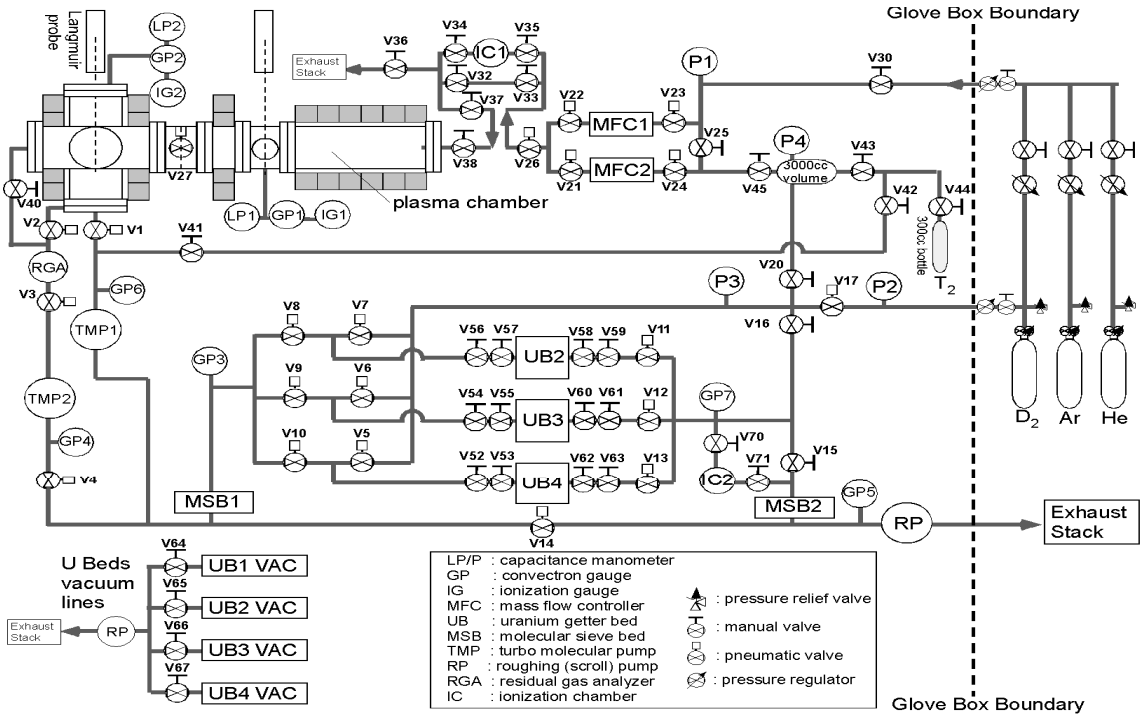

Figure 1: The schematic of TPE gas flow system

II.B. Tritium handling system in TPE

II.B.1 Tritium inventory and tritium safety considerations in safety tritium applied research (STAR) facility

STAR facility is classified as radiological facility, which is restricted to a facility total tritium inventory of less than 16,000 Ci (~1.6 gram) of tritium, the threshold limit for a Hazard Category 3 Nuclear Facility. To ensure compliance with this limit, the tritium inventory is administratively controlled to 15,000 Ci[2]. TPE utilizes three confinements to contain the radioactive tritium: stainless steel piping as the first confinement, the negatively-pressurized glovebox as the second confinement, and the negatively-pressurized room as the third confinement. Three depleted uranium getter beds are used for the purpose of minimizing the release of tritium to the environment as illustrated in Figure 1. The maximum use of tritium in TPE is limited to 500 Ci (0.05 gram) in each experiments, therefore, tritium is used as a trace gas in most experimental cases.

II.B.2. Tritium supply, tritium pumping system and depleted uranium getter beds

Tritium is typically supplied as gas form in 300 cc transfer bottle from the STAR Storage and Assay System. The maximum capacity of tritium in each transfer is approximately 600 Ci. The tritium transfer bottle is mounted inside the glove box as illustrated in Figure 1. The 3000 cc volume is pressurized with deuterium to approximately 1200 Torr prior to the mix with tritium, and the deuterium/tritium mixture is created by opening valve V43 and V44. The tritium concentration in the TPE is determined by controlling the flow rates of pure deuterium (MFC1) and the deuterium/tritium mixture (MFC2), and is monitored by a ion chamber (IC1) located downstream of MFCs. The TPE chamber is pumped by a turbo molecular pump (TMP) with a pumping speed of 1000 liter/s, and a base pressure is 1.3×10^{-5} Pa (1×10^{-7} Torr) after bake-out. The TMP is backed by a 8.3 liter/s oil-free roughing (scroll) pump (RP). Three depleted uranium beds (UBs) are located in between the TMP and RP, and each UB contains 1.27 kg of ^{238}U. The exhaust gas containing tritium from TPE is guided through the UBs for the purpose of minimizing the release of tritium to the environment.

II.C. Tritium depth profiling up to mm range

II.C.1. Tritium imaging plate (TIP) technique

The tritium distributions on both plasma-exposed surface and the cross-sectional surface were measured by a TIP technique, and the details of the TIP technique were described in elsewhere[3,4]. The TIP utilizes the detection of beta election emitted from tritium in a certain depth, and provides the tritium concentration profiles with a resolution of 25 μm. The TIP exposure times are 2 hour and 24 hours, for the plasma-exposed surface, and the cross-sectional surface, respectively.

II.C.2. Diamond wire saw (DWS)

Fine diamond wires (less than 100 μm in diameter) are used in the DWS with low wire speed about 2 m/s. Long diamond wire (~ 10 m) is continuously wound on a metal cylinder to dissipate the residual heat, and DWS cuts materials without appreciable heating of the materials (up to 10-20 K), allowing us to cut the tritium implanted samples without desorbing tritium significantly. Figures 2 (a) and 2(b) show 2D images of tritium profile in W before and after cutting with DWS, respectively. Note that large and small dotted lines denote the sample area and the plasma-exposed area, respectively. Figure 3 shows radial profiles of tritium concentration in W. Dotted and solid lines denote before and after cutting with DWS. The 1D profiles were obtained by integrating over 1mm width in radial (x) direction as illustrated with solid line in Figure 2. Figures 2 (b) and 3 show that the DWS cut width is less than 500 μm, and conform that the DWS is able to cut the tritium implanted samples without desorbing tritium significantly. Therefore, DWS is used to cut the tritium planted tungsten to investigate tritium depth profiling in bulk tungsten.

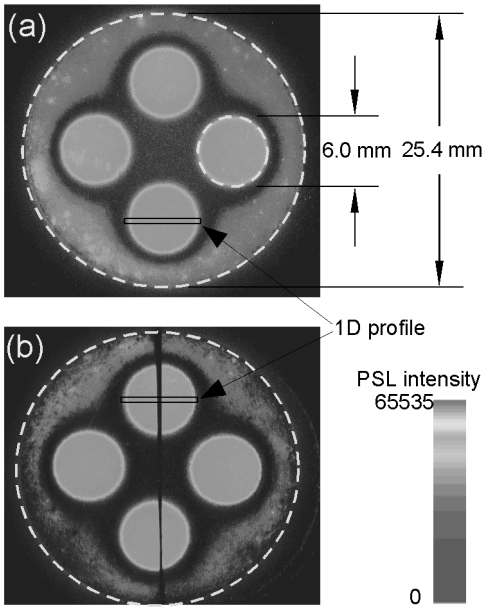

Figure 2: 2D images of tritium profile in W exposed to high flux tritium/deuterium plasma in TPE. (a): before cut, (b): after cut. Large dotted line, small dotted lines, and solid line denote the sample area, the plasma-exposed area, and the area used for 1D profile, respectively.

III. RESULTS

III.A. TIP using split sample

As a preliminary experiment a set of split sample (cylindrical samples that were cut in half prior to the experiments) was used in order to examine the sensitivity of TIP measurement and to investigate the depth range of tritium migration in the bulk tungsten[3]. The W split samples (diameter: 6 mm, thickness: 10 mm) were tightly put together, and one side of circular surfaces was exposed to deuterium/tritium plasma for 2 hour at 573 K and 393 K. The incident ion flux density, ion fluence, and ion energy were approximately 10^{21} $m^{-2}s^{-1}$, 10^{25} m^{-2}, and 100 eV, respectively. The tritium/deuterium ratio was approximately 0.2% T_2/D_2. Figures 4(a) and 4(b) show the 2D image of W split samples exposed to TPE for 2 hour at 573 K and 393 K, respectively. The plasma-exposed area was approximately 5.5 mm in diameter at z=0 location, and the 1D profile were obtained by integrating over 5.0 mm width in axial (z) direction as illustrated with solid line in Figure 4. Figures 4 (a) and 5 show the tritium can be migrated up to 3 mm, therefore, the thickness of the bulk sample was chosen to be 3 mm in order to minimize the cutting time. The 1D profiles from the W split samples at 573 K and 393 K are shown in Figure 5. It is important to note that the purpose of this preliminary experiment using the split samples was to examine the sensitivity of TIP measurement and the depth range of tritium migration for the following experiments using diamond wire saw.

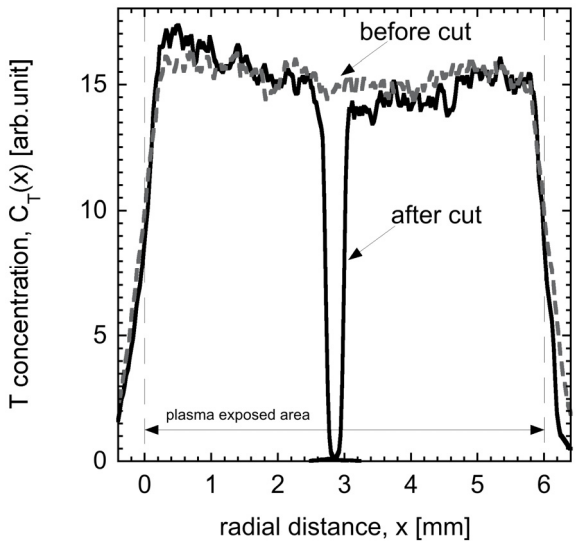

Figure 3: Radial profiles of tritium concentration in tungsten

III.B. TIP using diamond wire saw

As a succeeding experiment a set of bulk sample (cylindrical samples, diameter: 25.4 mm, thickness: 3 mm that was determined from the preliminary experiment) was used to obtain the tritium depth profile up to mm range. One side of circular surfaces was exposed to deuterium/tritium plasma for 2 hour at 473 K and 773 K. The incident ion flux density, ion fluence, and ion energy were approximately 10^{21} $m^{-2}s^{-1}$, 10^{25} m^{-2}, and 100 eV, respectively. The tritium/deuterium ratio was

approximately 0.5% T_2/D_2. Figures 4(c) and 4(d) show the 2D image of W bulk samples exposed to TPE for 2 hour at 473 K and 773 K, respectively. The plasma-exposed area was approximately 6.0 mm in diameter at z=0 location, and the 1D profile were obtained by integrating over 5.0 mm in axial (z) direction as illustrated with solid line in Figure 4. The 1D profiles from the W bulk samples at 473 K and 773 K are shown in Figure 5.

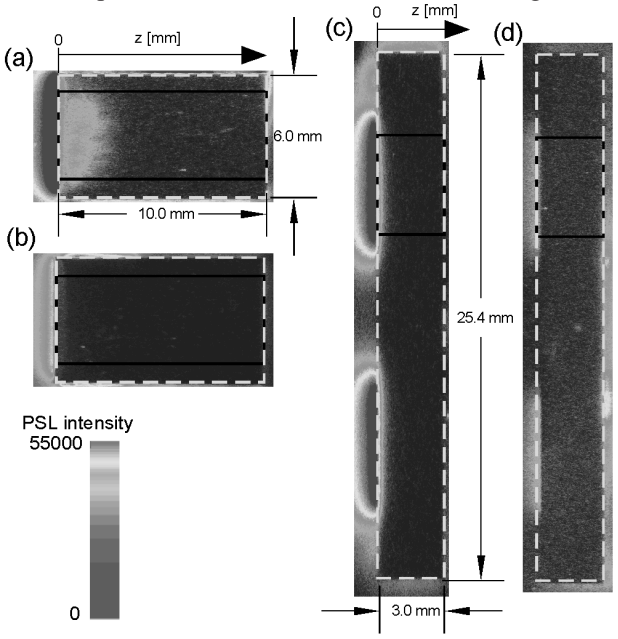

Figure 4: 2D images of tritium profiles in W (a): split sample exposed at 573 K, (b): split sample exposed at 393 K, (c) bulk sample exposed at 473 K, and (d) bulk sample exposed at 773 K. Dotted and solid lines denote the sample area and the area used for 1D profile, respectively.

IV. DISCUSSIONS

Figure 5 illustrates the 1D profiles from both the W split sample exposed at 573 K and 393 K, and the W bulk samples exposed at 473 K and 773 K. Unfortunately the identical sample temperatures were not obtained due to the differences in the sample thickness. The 1D profiles from split samples have complex diffusion profiles compared with that from bulk samples, indicating the complex nature of tritium behavior in split samples (tritium migration from the gap, tritium diffusion out from cross sectional surface during the cooling down after TPE exposure). Figure 5 also shows that the simple diffusion depth profile up to 2 mm was observed from the bulk sample exposed to 473 K, indicating the validity of the depth profiling method using TIP and DWS.

V. CONCLUSIONS

A tritium depth profiling method up to mm range was developed using TIP and DWS. A series of tritium experiments (T_2/D_2 ratio: 0.2 and 0.5 %) was performed to investigate tritium depth profiling in bulk tungsten, and the results shows that tritium is migrated into bulk tungsten up to mm range. This is a promising technique to investigate tritium behaviors in entire PFCs thickness (mm to cm range) of the ITER divertor and first wall.

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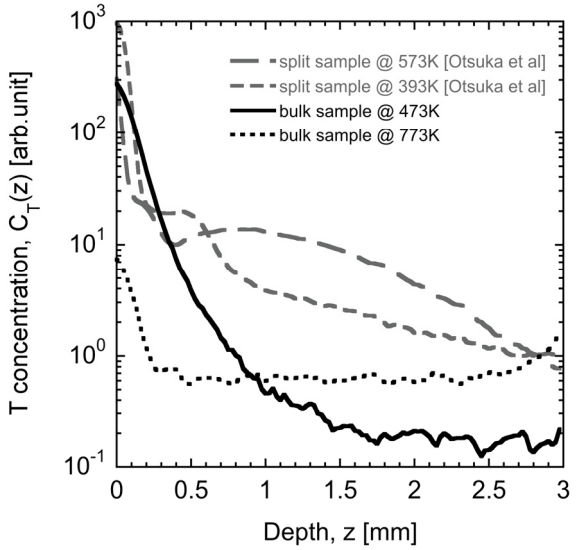

Figure 5: Depth profiles of tritium concentration at different temperatures in W.

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